Visuomotor Skill Learning: a PET Study of Mirror Tracing Using Cluster Analysis and Statistical Parametric Mapping

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Introduction. Functional imaging studies of motor learning have focused on brain regions where the activity changes linearly with the speed or accuracy of performance. However, such an approach may overlook sites where the relation between the neural activity and the learning curve is more complex.

In order to identify brain regions involved in the acquisition of mirror tracing skill, we included in the analysis an exploratory step to investigate the temporal signal of functional activation over 11 practice trials.

Methods. Eighteen right-handed healthy volunteers participated in the study. Eleven $H_2{}^{15}O$ PET scans were acquired over 11 tracing trials: 3 trials of normal tracing followed by 8 trials of mirror tracing. During each 60 seconds trial, the subjects viewed a six-pointed star on a computer screen and traced the star path using a mouse controlled by their left index finger. During mirror tracing the movements of the cursor on the screen were mirror reversed relative to the movements of the finger. The speed (cycles /minute) and accuracy (percentage of tracing time outside the path) were recorded.

Data from the first 9 subjects underwent cluster analysis using a k-mean algorithm from "lyngby" toolbox (1) that assigned the time series for each voxel to 10 clusters based on the Euclidean distance as measure of similarity.

The mean time series for each cluster were modeled as covariates in the design matrices of the subsequent SPM analyses, performed on data from the last 9 subjects.

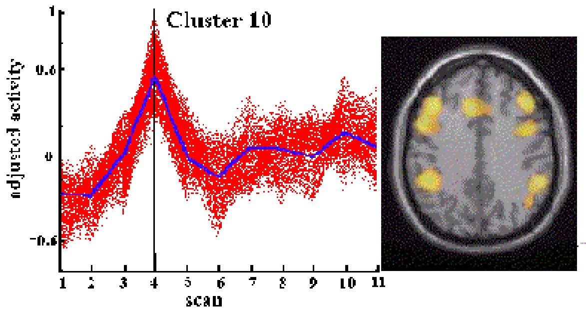
Results and Discussion. Three main trends in the temporal patterns of functional activation were identified by inspection of the cluster centers: a maximum /minimum of the activity signal in the first mirror tracing trial (indicated by a vertical line on the figure), analogous to the learning curves, and an increase of activity over all trials that did not parallel the variation of either speed or accuracy of tracing.

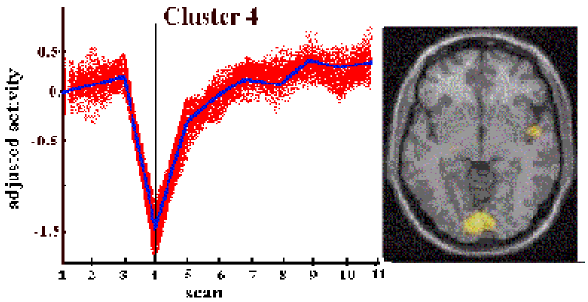
The spatial locations where functional activity was positively correlated with the mean time series (SPM, $p<0.05$, corrected for multiple comparisons) are illustrated to the right of the corresponding activity-vs-scan plots.

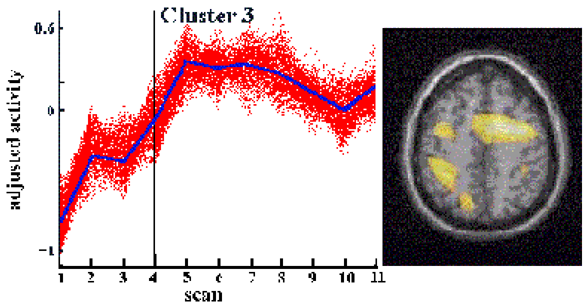
Cluster 10: bilateral in the cortex of the inferior frontal gyrus, anterior cingulate gyrus and inferior parietal lobe. These sites have previously been shown to activate in the early stages of motor learning (2).

Cluster 4: in the visual cortex mainly on the left side.

Cluster 3: in the cortex on both sides of the precentral sulcus, in the medial frontal gyrus and along the intraparietal sulcus bilaterally, at coordinates that were similar to the coordinates found in a previous PET study of visuomotor learning (3). Since these sites play a role in visuomotor transformations in monkeys (4) and are critical for the acquisition of visuomotor skills during mirror tracking (5), it is likely that the observed activity is related to the learning process.







Conclusion. Learning during mirror tracing engages a network of neurons in the premotor, supplementary motor and posterior parietal cortex, which transforms visual cues into appropriate directions of movement. However, the usual measures of performance (velocity, accuracy) were poor predictors of the activation signal recorded from these regions. This temporal signal might reflect cognitive processes with no clear-cut behavioral correlate such as mental rotation or the processing of a modulated visual input. An exploratory stage in the analysis of functional images is therefore necessary to identify temporally varying signals and provide a detailed picture of brain activity during visuomotor learning.

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